Tutorial 4.5 — Alpha Spectrometry 2: Calibration and Calculations

Slide 1. Alpha Spectrometry 2: Calibration and Calculations
This is the second of two modules in alpha spectrometry.

Slide 2. Learning Objectives
In this module you will learn how to:

- Describe the principles for calibrating an alpha spectrometer.
- Calculate the efficiency of an alpha detector.
- Calculate the alpha activity of a sample in the presence of a tracer.
- Discuss how the terms "efficiency," “decay factor,” and “abundance factor” are applied to the analytical calculation.

The equations shown on this slide represent the Key Concepts of detector calibration and alpha activity computation. Also of significance is that the efficiency of detection using a solid state detector is equal for alpha particles of all energies.

Slide 3. Spectrometer Calibration
The first step in calibration is to **energy** calibrate the detector. This is very important in correctly identifying which alpha emitter is present. The alpha spectrometer has 4096 locations where the information regarding the pulse height is stored. Remember that the pulse height is directly proportional to energy of the alpha particle. These locations are called channels, and the channel number is directly related to the energy.

At least two alpha particles of different energy are required to calibrate the detector.

Slide 4. Alpha Spectrum of Two Known Standards
The graphic shown here displays a standard that contains two radionuclides having alpha particle energies that are significantly different. The channel in which the maximum number of counts accumulated for each separate alpha peak is associated wit that alpha particle energy. It is important to check that the resolution of these peaks (as measured by the full width half-maximum, FWHM) to ensure that they have the proper shape. If they are too wide the peak maximum will be recorded in a lower energy channel causing the energy calibration to be biased.

For this spectrum the peaks have acceptable FWHM, of about 70 keV.

Slide 5. Energy vs. Channel Number Determination
The energy calibration relies on the fact that when the total alpha particle energy is deposited on the detector the resulting electronic pulse is directly proportional to the particle energy. Thus the size of the individual pulse is used to identify the energy of the individual alpha particle. This will be very linear.

Slide 6. Energy Offset Equation
The standard equation for a straight line is used to calculate the energy per channel. Having two points and knowing that they are related to a linear function allows you to calculate the slope of the line as shown in the next slide.

Slide 7. Test yourself Exercise #1
The information necessary to perform a calculation of the slope of the line for energy calibration is shown here. Once you have computed the slope use one of the points and the slope to calculate the y-intercept using the y = mx + b format. Use this information and the hint to the right to calculate the slope and check your answer on the next slide.

Slide 8. Solution to Exercise 1
The slope is calculated to be 11.4 kev/channel.

If we take this and substitute into the y = mx +b equation we calculate the y-intercept as 4010 keV.

Using this information we can now predict in which channels other alpha particle energies will have their maximum. The example shown is for ^{240}Pu.

Slide 9. Determinants of Detector Activity
The solid state alpha detector is designed to absorb all the energy deposited by an alpha particle and convert it to an electrical pulse whose magnitude is proportional to the energy absorbed. Please note the following:

- The detector surface and the sample are maintained under a high vacuum. This eliminates the degradation of alpha particle energies by interactions with air "molecules."
- Also because every alpha particle that hits the detector is stopped by the detector (causing a pulse), the efficiency for the detector is constant regardless of the incident alpha energy. But remember that the actual pulse height depends on energy, so we have means of distinguishing between different energies.
- The maximum efficiency for this type of set up approaches 50% because the emission of alpha particles from the sample test source is isotropic (equal in all directions). However is unlikely to achieve an efficiency of 50% because it requires a large detector and a small source. The ideal source would be a tiny "point," like the tip of a pin. Typical efficiencies range from ~ 20% to 35 %.

Slide 10. Calculating Detector Efficiency
As an example, here is the data from counting a calibration source with 203 dpm of Pu-239. The source was counted for 50 minutes and the background count was zero. The Pu-239 peak had 3010 counts. The efficiency of counting that is the ratio between the observed counts per minute and the known activity for the ^{239}Pu is shown in the solution to this equation.

Slide 11. Test Yourself Exercise #2

A ^{242}Pu test source has been counted and 3755 counts have been recorded in a 50 minute count interval. The detector background for the same counting interval without the test source is zero counts. The initial sample had 251 dpm of ^{242}Pu. Calculate the detector efficiency and check your results with the answer on the next slide.

Slide 12. Test Yourself Exercise #2 Solution

Did you get 0.299 as the efficiency? Note that the units can be in cpm, dpm, pCi or any other units as long as they are the same in the numerator and denominator. The efficiency is a dimensionless quantity.

Slide 13. Alpha Detector Efficiency

The efficiency of an alpha detector will be the same for each alpha particle regardless of energy. This is based on the construction of the thin barrier covering the detector surface and the sample being placed in a vacuum chamber. All the alpha energy will be deposited within the active area of the detector to yield a signal one alpha yields one pulse, but the size of that pulse will depend on the alpha particle energy.

Slide 14. Alpha Spectrometer Schematic

The concept shown here is that both alpha particles regardless of energy will lead to one count being recorded. However, the higher-energy alpha will lead to an electronic pulse in an external circuit that is larger that that of the lower energy alpha. Thus, the particles may be distinguished by their pulse size.

Slide 15. Activity Correction Factors

The measured activity of the sample test source must be corrected for physical parameters of the radionuclide and the detector. The three factors are the radionuclide decay from sampling to separations to counting, the alpha particle abundance factor and the detector efficiency. We will discuss these three factors separately in the next slides.

Slide 16. Detector Efficiency Factor

For those analyses where a suitable tracer is available, the efficiency term cancels out in the final equation because the efficiency for alpha particles of different energies is the same. However, when performing analysis for radium-226 or polonium-210 where no suitable tracer is generally used, the efficiency must be taken into account.

Slide 17. The Decay Factor

Two other correction factors are included. The first one accounts for the decay of the tracer and the radionuclide being determined. The tracer must be corrected for its activity loss from its reference date and time to the midpoint of the counting period, and may not be significant for a long-lived tracer and thus may be estimated to be equal to one. This may also be true for the radionuclide being determined. Usually longer than 50 years.

Slide 18. The Abundance Factor
The second term corrects for the probability of alpha emission per decay of the tracer being different from one. Note that for plutonium and uranium the abundance factors are not one for each alpha emitted. This simple means that the number of alphas that we measure at a certain energy represents only a fraction of the total number of atoms that have decayed.

Slide 19. General Equation for Calculating Activity
This is the general equation used to calculate the activity of the analyte in the sample by correcting the activity of the analyte found on the sample test source for the radiochemical yield. The net count rate of the analyte is converted to the activity of the analyte in the source by applying the radiochemical yield (which is the measured activity of the tracer divided by the true concentration), decay correction for the analyte, and probability of alpha emission of the analyte, and any unit conversions.

Note that the efficiency does not appear in this equation because the efficiency of detection of all alphas in a solid state detector is the same.

Slide 20. Simplified Alpha Particle Activity Equation
When you combine the two previous equations, and assume the correction factors for decay (D_t and D_a) and for probability of alpha emissions (I_t and I_a) are all equal to 1, the final equation is very simple and does not include detector efficiency. This will always be true for alpha spectrometry as long as we assume that the detection efficiency for alpha particles is independent of their energies.

You may also note that the units for count rate can be anything, as long as they are the same for the analyte and the tracer.

Slide 21. Test Yourself Exercise #3
As an example, here we have data available from the analysis for U-238, using alpha spectrometry and U-232, an alpha emitter, as a radiochemical tracer.
Calculate the activity of ^{238}U.

When you have completed your calculation compare the result with that on the next slide.

Slide 22. Test Yourself Exercise 3 Solution
Did you get 0.952 pCi? If not review the calculation on this slide to see where you went awry.

Slide 23. Conclusion
At this point you should be able to:

- Describe the principles for calibrating an alpha spectrometer.
- Calculate the efficiency of an alpha spectrometer.
- Discuss when it is or is not necessary to include correction factors for efficiency, decay, and abundance when calculating the amount of an alpha-emitting radionuclide in a sample.

- Calculate the amount of an alpha-emitting radionuclide analyzed in the presence of a radioactive tracer.